

AN ADVANCED APPROACH FOR BETTER MECHANICAL PROPERTIES OF EPOXY BASED CARBON COMPOSITES USING DOUBLE VACUUM BAG INFUSION TECHNIQUE

Ashfaq Hussain

Composite Research Center, Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

School of Mechanical Engineering, Xian Jiaotong University, Shaanxi, Xian P.R.China

M.Faizan Siddique Awan

^aComposite Research Center, Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

Kalsoom Bhagat

Department of Electrical Engineering, MUET SZAB Campus Khairpur, Sindh, Pakistan

Laraib Alam Khan

^aComposite Research Center, Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

Kashif Naveed

^aComposite Research Center, Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

Tayyab Subhani

^aComposite Research Center, Department of Materials Science and Engineering, Institute of Space Technology, Islamabad, Pakistan

Note: This paper has been accepted for publication from the submissions made at the 2nd National Conference on *Intelligent Manufacturing & Sustainable Energy Systems (IMSES 2016) - Pakistan*

Abstract

Double vacuum bag (DVB) infusion process is used for the manufacturing of carbon fiber epoxy matrix composites for aerospace applications. For reference, carbon fiber epoxy matrix composites were also prepared by single vacuum bag (SVB) infusion process. The composites manufactured by DVB showed less void contents and more fiber volume fraction together with good impregnation of carbon fibers with resin. An increase in mechanical properties including shear and flexural moduli was also observed than composite processed by SVB. DVB infusion process is a promising technique for the manufacturing of polymeric matrix composites for aerospace and automobile industries.

Keywords: Double vacuum bag; Single vacuum bag; Carbon fiber; Epoxy resin.

1 INTRODUCTION

Polymer matrix composites (PMCs) are an important class of engineering materials. PMCs are successfully replacing traditional structural materials and offer an opportunity to compete metallic materials^[1]. In particular, carbon fiber epoxy matrix composites are especially used for aerospace applications due to their better specific properties than traditional materials. Carbon fiber epoxy matrix composites have gained importance due to their higher strength-to-weight ratio. Carbon fibers may exist in short fibers or continuous forms. The structure may be amorphous, crystalline or partly crystalline. Moreover, carbon fibers do not impart health hazards^[1].

The properties of PMCs are dependent on the mode of fabrication. Tooling design is vital for the production of cost-effective and durable composite products^[2]. A range of processes have been developed to prepare PMCs such as hand layup, spray up, compression moulding, transfer moulding, vacuum infusion and vacuum bagging^[3]. In particular, close mould techniques were developed to fabricate composite parts with less damage to human health and better functional and structural properties^[4, 5]. Close mould methods utilize two counterparts, i.e. a male part and a female part. A variant of closed mould process is resin transfer moulding, which has further variants such as vacuum assisted resin transfer moulding. Another variant is controlled atmospheric pressure resin infusion^[6, 7].

Among different manufacturing techniques, vacuum infusion is a process widely used to prepare PMCs, which offers a safer and affordable alternative to produce composites otherwise prepared by autoclave processes^[8]. In this technique, consolidation force is applied via vacuum, which derives low viscosity resin into the mould cavity. Like other techniques, vacuum infusion also has limitations associated with it such as the presence of voids in composites, bag relaxation defects and non-uniformity and permeability issues.

Double Vacuum Bag (DVB) infusion technique is an easy and cheap technique to fabricate quality PMCs than other techniques. In single vacuum bag (SVB) process, the polymeric bag provides compaction which is not sufficient to achieve good densification of composites. The parts fabricated from SVB process are found to have high void contents. The properties of a composite are detrimentally affected by voids introduced during the manufacturing process. SVB process along with the porosity factor produce composites having fiber volume fraction in the range of 40-43%. As the main properties of PMCs are derived from fibers, therefore, their increased content in composites is advantageous. Higher the fiber volume fraction in a composite, higher will be the strength and modulus; thus, increased efficiency and performance of the composite. DVB works on the same principle of infusion and utilizes two separate bags under two vacuum levels. The actual infusion takes place in the inner bag. The second bag seals the mould and envelops the first bag and provides extra pressure on the infused composite part. As the resin enters the first bag the absolute pressure drops with the increase in the volume. The double bag tries to compensate by providing full vacuum pressure to the part, hence allowing the removal of extra resin, increased fiber content and a lower void content.

In this paper work on DVB technique is used to prepare composites. The aim is to produce void-free composites and to increase their integrity thus producing parts with higher fiber volume fraction. A comparison between DVB and SVB was made on the basis of physical and mechanical properties i.e. void content, fiber volume fraction, shear modulus, flexural modulus. Carbon fibers were impregnated in epoxy resin to prepare composites by the both techniques for comparison. Microstructural and mechanical characterization was performed to evaluate the composites with reference to their manufacturing techniques.

2 EXPERIMENTAL

Materials

Commercially available, high-strength polyacrylonitrile-based 2-D woven carbon fabric with average fiber diameter of 7 μm was procured from CNME International, China. Epoxy resin (Araldite 5052) with its hardener (Aradur 5052) was purchased from Huntsman Advanced Materials. Airtech peel ply, distribution media, and polymeric nylon bag were used for composite manufacturing. Caul plate was used to acquire even compaction upon carbon fabrics; two rotary vacuum pumps were used.

Manufacturing

Flat and rectangular composite panels of dimensions 500x400 mm were fabricated using DVB and SVB processes. The mould was cleaned with acetone, which was followed by the application of demolding material, i.e. wax. Peel-ply was first placed in the mould cavity, which served as a debonding media and helped to debond the final composite specimen from the mould without sticking. The carbon fabrics in desired dimensions were later stacked in the mould. After placing the desired layers of carbon fabrics, another layer of peel-ply was stacked above the carbon fabrics; as a matter of fact, carbon fibers were sandwiched between two peel-pplies. Highly permeable distribution/flow media was placed over peel ply, which is a mesh-like structure and helps the resin to distribute homogeneously over the preform, i.e. carbon fabrics. Subsequently, a polymeric bag covered the mould containing carbon fabric; the bag was attached with the substrate using a tacky tape.

A perforated metal plate with smooth surface finish was placed over the bag, which served as caul plate. Ideally, caul plate should be equal in size to the size of fabrics to distribute equal pressure upon the composite to be manufactured. Another polymeric bag was used, which covered the existing setup and was also attached to the substrate using a tacky tape. In the inner bag, an inlet and an outlet were prepared for the infusion of the resin. Inlet port was connected to the resin pot via a plastic pipe. The outlet port connected with the resin reservoir has two holes: one connected with the vacuum pump and other with outlet pipe. The present setup ensured the backflow of resin to vacuum pump, which might cause failure of the pump. For outer bag, a single outlet was connected to a second vacuum pump through a pipe.

Before the infusion to start, the valve on the inlet pipe was closed. The vacuum pump was switched on to evacuate the air from the setup. When mold was completely degassed, the setup was checked for any leakages. The resin was also degassed for 15 min. After complete checking and degassing, the inlet pipe was placed in the resin pot and inlet was opened. Due to the action of atmospheric pressure resin started flowing into the mold. Due to high compaction and use of permeable flow media, the resin was equally distributed over the whole composite specimen and complete wetting of the fabric was obtained. Vacuum pump sucked the excess resin while the process continued for 2h to remove excess resin from the part. Finally, the vacuum pump was switched off. After curing of composites for 24h, these were removed from the mold and post-cured in an oven at 100°C for 1h. Figure 1 shows the schematic of the composite manufacturing process. For comparison composites with conventional SVB process were also prepared.

Characterization

Images of the composites were captured using an optical microscope. To determine void concentration and fiber volume fraction, image processing of the composite images was carried out using Image J software. Moreover, the void size, shape, and spatial distribution were also determined using the composite images.

Mechanical properties of the prepared composites were evaluated from interlaminar shear and three-point bend tests. Shear test was performed according to ASTM D2344 standard with specimen size of 15x10x10 mm. Three-point bend test was performed using ASTM D790 standard with specimen size of 80x15x10 mm. At least ten specimens were prepared for the two testing techniques to acquire reliable data.

3 RESULTS AND DISCUSSIONS

Optical micrographs of the composites processed by DVB and SVB and their image processing are shown in Figures 2 and 3, respectively. The difference in the void contents can be seen. Indeed, the presence of defects in composites such as porosity and voids reduces their mechanical performance, as discussed further below.

Table 1 enlists the physical and mechanical properties of the composites manufactured by DVB and SVB processes i.e. void content, shear, and flexural moduli. In comparison to SVB, the process of DVB offers better compaction and higher loading of fibers. It can be seen in Figure 4 that the average void content in SVB-processed composites is 11 ± 2 , which reduced to 4 ± 2 in DVB-processed composites. The decrease in void content was achieved after increased infusion of resin under high pressure in DVB process. Moreover, the fiber volume fraction also increased under high pressure. After proper impregnation of fibers, the excess resin was rejected by the process. Figure 5 shows the increase in the fiber volume fraction in the two manufacturing processes. It can be seen that the fiber volume fraction increased from 42 ± 3 to 54 ± 3 , when DVB process was used.

It was obvious that composites containing less porosity and increased fiber contents possessed better mechanical properties, which was evidenced in mechanical testing. The composites processed by DVB offered higher flexural modulus, i.e. 51 ± 3 GPa than reference composites, i.e. 44 ± 3 MPa (Figure 6a). Similarly, shear modulus of the composites manufactured by DVB was higher, i.e. 44 ± 3 GPa than reference composites processed by SVB, i.e. 37 ± 3 GPa (Figure 6b). It can be inferred that the composites fabricated by DVB offered more control over vacuum and resulted in better mechanical properties. Moreover, low void content means better structural properties due to better integrity of manufactured composites.

When resin enters the dry carbon fabrics under pressure, it may displace fibers. Hence the void concentration in such areas will be high, which was verified by optical images (not shown here) that void concentration is different at different locations of the composites. The resin flow is uniform in the middle of the composites while the edges have increased void contents. The same trend was observed in the composites processed by both techniques though the effect was diluted in DVB process, as observed in Figure 7, which shows the void content measurement from one edge of the composite specimen to the other edge with a distance of 500mm. Vacuum leakages may occur at the edges and result in high void content but DVB process provided better vacuum control and therefore the void concentration was much lower than SVB process.

4 CONCLUSIONS

Double vacuum bag (DVB) infusion process was adopted for the fabrication of polymeric matrix composites. Carbon fiber epoxy matrix composites were selected for the fabrication of composites and a comprehensive comparison was drawn between the physical and mechanical properties of the composites prepared by DVB and single vacuum bag (SVB) infusion processes. An increase in the mechanical properties, i.e. shear and flexural moduli, was noticed using DVB process. The void contents also decreased by using this novel process along with an increase in the fiber volume fraction in the composites. Finally, it was observed that the application of double bags reduced the difference in void contents at the middle and edges of the composites and provided materials with better resin impregnation and thus uniform resultant properties.

TABLES

Table 1. Mechanical properties for SVB and DVB samples

Samples	Void Content (%)	Shear Modulus (GPa)	Flexural Modulus (GPa)
SVB	10±3	37±3	44±3
DVB	4±2	44±3	51±3

FIGURES

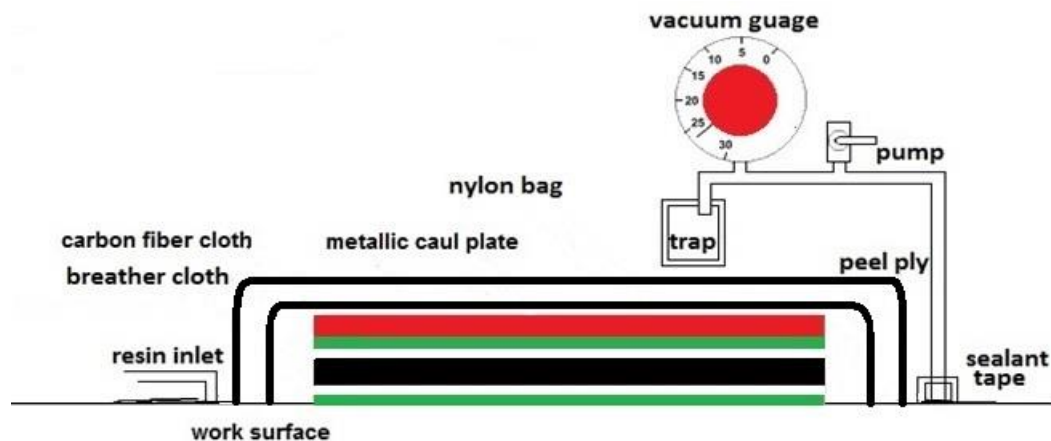


Figure 1 Schematic illustration of double vacuum bag infusion process

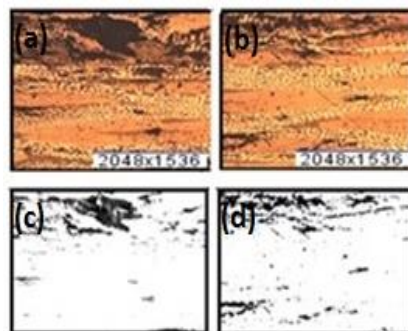


Figure 2(a,b) Optical micrograph of composites prepared by SVB and (c,d) their image processing

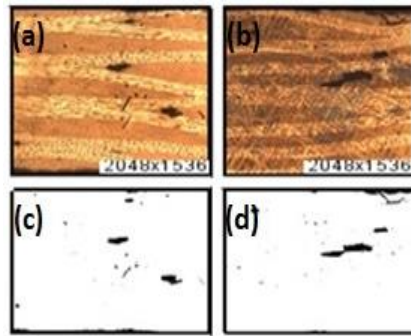


Figure 3 (a,b) Optical micrograph of composites prepared by SVB and (c,d) their image processing

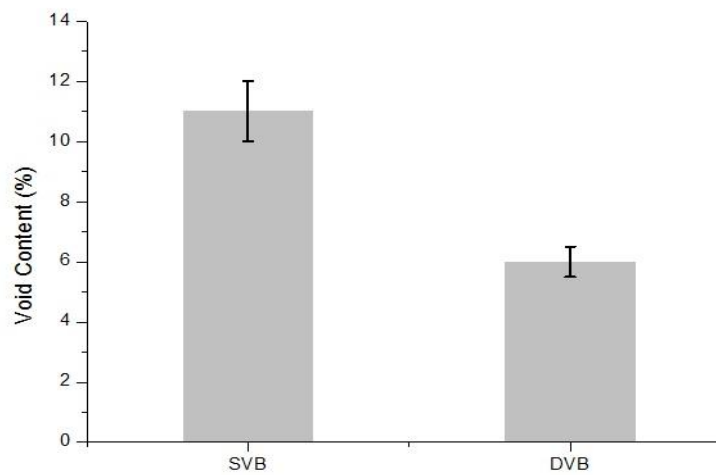


Figure 4 Void concentration in DVB and SVB process

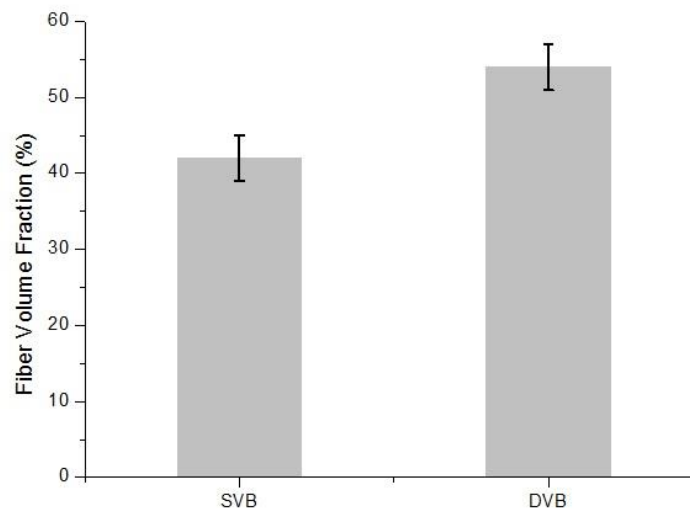


Figure 5 Fibre volume fraction comparison graph

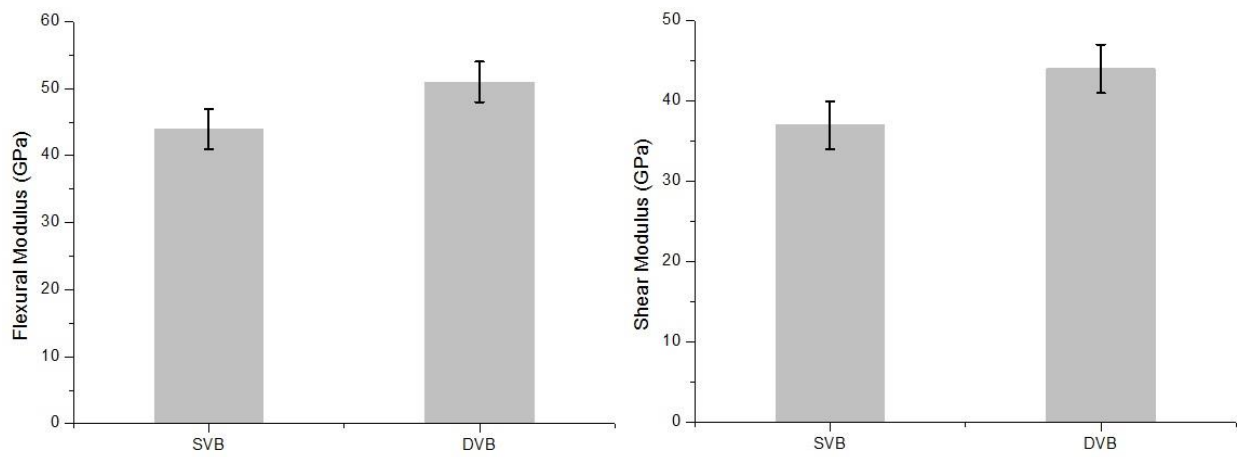


Figure 6 Modulus comparison for DVB and SVB process (a) flexural modulus (b) shear modulus

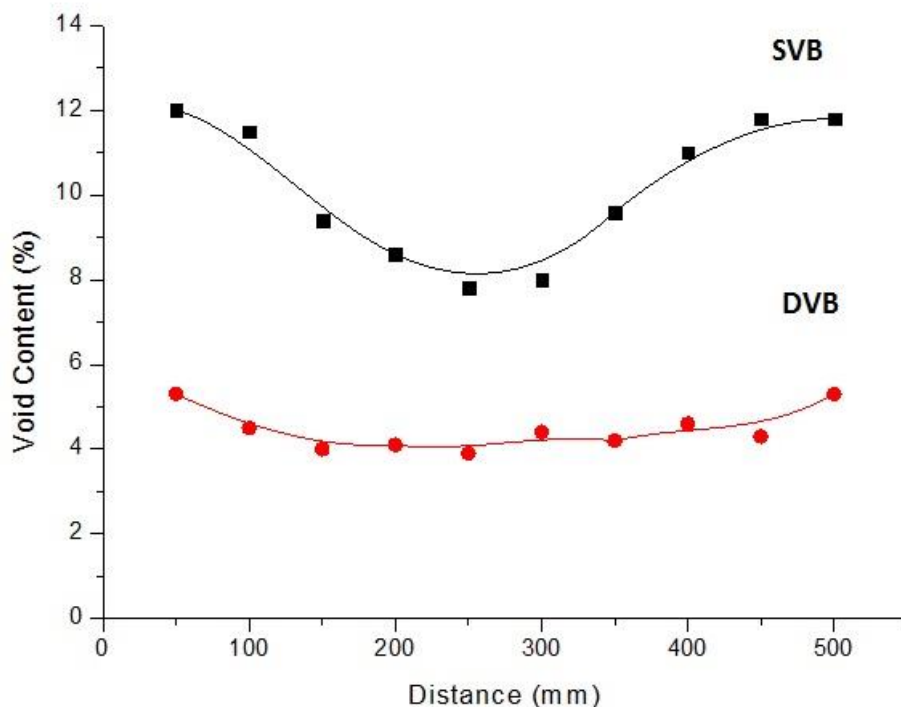


Figure 7 The spatial distribution of void contents in composites manufactured by SVB and DVB processes

References

1. Singha, K., A Short Review on Basalt Fibre International Journal of Textile Science 2012.
2. Abdalrahman, r., design, and analysis of integrally-heated tooling for polymer composites. 2015.
3. McIlhagger, A., E. Archer, and R. McIlhagger, Manufacturing processes for composite materials and components for aerospace applications. Polymer Composites in the Aerospace Industry, 2014. 53.

4. Ho, M.-p., et al., Critical factors on manufacturing processes of natural fiber composites. Composites Part B: Engineering, 2012. 43(8): p. 3549-3562.
5. Michaud, V. and A. Mortensen, Infiltration processing of fiber reinforced composites: governing phenomena. Composites Part A: applied science and manufacturing, 2001. 32(8): p. 981-996.
6. Rudd, C., et al., Liquid moulding technologies: Resin transfer moulding, structural reaction injection moulding and related processing techniques. 1997: Elsevier.
7. Niggemann, C., et al., Experimental investigation of the controlled atmospheric pressure resin infusion (CAPRI) process. Journal of Composite materials, 2008. 42(11): p. 1049-1061.
8. de Almeida, S.F.M. and Z.d.S.N. Neto, Effect of void content on the strength of composite laminates. Composite structures, 1994. 28(2): p. 139-148.